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The Pollution Haven Hypothesis, a Dynamic Perspective

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Abstract

In this paper we build a dynamic trade model to investigate the relation between trade and the environment in a dynamic setting. We extend a trade model similar to Copeland & Taylor (2003) by adding capital accumulation. We characterize optimal environmental policy in autarky and under international trade. Then we analyze the effects of parameter differences across countries on steady state specialization patterns.

Keywords: Trade and the environment, Two-sector growth models.

JEL Codes: F18, F43, O41, Q56.

1 Introduction

Today, a couple of decades into their industrial revolutions, China has 1.3 billion people and India 1.1 billion. What these two countries jointly pursue is growth on a scale that is more than 200 times larger than what the UK and the US managed during their industrial revolutions. Well-informed observers of Chindia argue that Chindia will avoid.. (environmental) disasters by learning to price ... scarce resources (especially water) appropriately. Chindia will not have a century or more to figure out how to make growth environmentally sustainable—a process still far from complete in the UK and the US. They have less than a decade.[Willem Buiter (2007), 'The Browning of Chindia'].

The 'East Asian Miracle' is a topic in recent economic history that has received considerable attention from the economic profession. It tells

an interesting story of a collection of export-oriented economies that have had high growth rates for more than three decades. It fits in a larger series of events in global economic development and encompasses various post-war economic trends. Among these trends that are confirmed by the empirical data are the conditional convergence of open economies, the increase in the volume of world trade and, in a seemingly whole other sphere of interest, the steady degradation of the global environment according to various ecological indicators. Conditional convergence explains how poor countries that are open to trade grow faster than their high-income partners. This process has been accompanied by increases in the volume of trade between high-income countries and the newcomers. It has, however, not yet been made clear how the various polluting industries, one of the root causes of global environmental degradation, are distributed across trading partners over time. So far this focus is understandable from an empirical point of view: the growth experience that we have referred to is that of a number of relatively small economies. Their joint impact on world aggregates, be it economic or environmental, is very modest.

None of this holds true whatsoever for the growth process of 'Chindia'; together, China and India hold more than 1/3th of the world's population. China's rise to its role as the 'manufacturer of the world', as it is often denoted in the popular press, is unprecedented in terms of both speed and scale. As with the East-Asian miracle, many argue that China's process of development is characterized by trade-led growth with growth rates that exceed those of its most important trade partners, the European Union and the United States, by several percent points.

Our analysis is a first attempt to capture these recent facts in economic history and, more generally, to provide for a dynamic perspective of the pollution haven hypothesis (PHH). The framework that we propose could be a first step towards a more comprehensive theory of pollution havens; one that pays particular attention to i) economic dynamics and ii) the increasing importance of international trade in the world economy, not only in final goods but also in intermediate goods, ideas, factors of production etc. This process of global integration is, in contrast to what some might think (see for example Friedman (2005)) not completed. From a theoretical point of view this implies that the world is still far from the hypothetical 'integrated world equilibrium' that trade theorists are so fond of (Dixit&Norman, 1981; Ventura, 2005). Therefore, our approach seems relevant.

This paper incorporates optimal saving and investment behavior into a $2 \times 2 \times 2$ Heckscher-Ohlin framework with environmental damage from pollution. With the dynamic trade model that is obtained we derive the

necessary conditions, related to demand side and supply side parameters, under which a country can become a net exporter of the dirty good, i.e. a pollution haven. We do this in a setting where (i) both sectors of production make use of a polluting factor of production, (ii) the pollution that is generated by production is local in nature and (iii) environmental policy is endogenous. Our paper adds to the literature by emphasizing the deeper determinants of specialization patterns and pollution havens, especially the subjective time discount rate. In the steady state the relatively impatient country might specialize in the dirty good. While some of our results relate to previous models in the literature, other results are new and provide for interesting avenues in future research. We also sketch how the model potentially could be extended to analyze some positive and normative questions related to income convergence, convergence of industry emission intensities and trade.

2 Overview of the literature

Our paper contributes to several strands in the literature. First, there is a by now enormous literature on the relationship between international trade and the environment. The main question here is whether trade, through its effects on the scale, the composition and the location of economic activity, is beneficial for the environment. Seminal contributions in this field are by Grossman&Krueger(1994), Copeland&Taylor (1994, 2003, 2004) and Antweiler et al. (2000). Copeland&Taylor (1994) analyze the relationship between trade and the environment in a North-South Ricardian trade model with a continuum of goods, following Dornbusch et al. (1977). They assume that North and South differ in terms of technology (or human capital). As a result North has a higher level of income. Under endogenous environmental policy the income difference implies that the North sets a more stringent environmental policy. This mechanism creates an income-induced comparative advantage for the North in the clean good. Due to its lower level of income and less stringent environmental policy the South becomes a net exporter of dirty goods. Thus, their model is an elaborate example of the pollution haven hypothesis; low-income, labour abundant countries will specialize in the production of dirty goods. In Copeland & Taylor (2003) the focus shifts towards the factor endowment hypothesis that states the exact opposite: high-income and capital-abundant countries will become a net exporter of dirty goods. It is now recognized that, at least in theory, these two countervailing forces that are exerted through a country's capital-labour ratio jointly determine the specialization pattern in open economies.

A second strand of the literature that is important for our work is concerned with capital accumulation in open economies. Since the interest

rate in open economies is determined by the terms of trade, the process of growth through capital accumulation is distinct from that in closed economies. Seminal publications in the field of dynamic H-O models are by Oniki&Uzawa (1965) and Stiglitz (1970). These authors assume exogenous savings rates as in Solow (1956). Cross-country differences in savings rates imply that, even though the long-term balanced growth rate is exogenous and equal to the rate of technological progress, the steady state capital-labor ratio will differ between countries. Thus, production patterns will be distinct even in the steady state. More recently Baxter (1992) and Ono&Shibata (2006), among others, have incorporated intertemporal optimization behavior to endogenize saving rates. Classical Ricardian properties such as perfect specialization reemerge in this context since the steady state interest rate, and therefore the capital-labour ratio, are fixed by the rate of time preference. This feature sets these models apart from their predecessors with exogenous saving rates. Dynamic H-O models are also being used for a variety of more specialized topics, such as endogenous growth with both human capital and physical capital accumulation (Bond et al., 2003), fiscal policy and global welfare analysis (Ono&Shibata, 2005), trade, growth and convergence (Ventura, 1997, Acemoglu&Ventura, 2002) and, finally, status-seeking and catching-up (Hu&Shimomura, 2007). Thus, the dynamic H-O model has become a very important tool for studying the short-run and long-run determinants of comparative advantage in relation to other important questions in dynamic economic theory.

Here we apply dynamic H-O theory to analyze the relationship between international trade and the environment with endogenous environmental policy. Our paper is somewhat related to a recent paper by Umanskaya & Barbier (2008). They introduce the concept of a true pollution haven: a situation in which a country specializes completely in the production of dirty goods. Remember that the standard definition of a pollution haven was less restrictive: 'A country that, because of its weak or poorly enforced environmental regulations, attracts industries that pollute the environment' (Deardoff, 2001). This definition, however, has nothing to say on the overall production pattern of a particular country. Umanskaya & Barbier (2008) use a static two-country trade model to show that true pollution havens can be obtained as the outcome of differences in factor endowments and income generated differences in environmental policy. Their result is caused by the assumption of sufficiently large differences in factor endowments such that factor price equalization is not obtained. Then the implications of the model are in line with Ricardian trade theory: at least one of the two countries becomes completely specialized. In our model we derive a dynamic version

of this proposition that is even sharper: an infinitely small difference in the subjective discount rate or technology assures that at least one country becomes a true pollution haven in the steady state.

This paper is organized as follows. Section 2 outlines our dynamic trade model. In section 3 we discuss the properties of the steady state in autarky. In section 4 we move to a situation with international trade. It is shown that even the slightest difference in the rate of time preference across countries will cause at least one country to specialize completely in the steady state. We derive necessary conditions for the various types of pollution havens and show some examples. In section 4 we explain how to extend the current model in order to study the effects of environmental policy on growth convergence. Section 5 concludes.

3 A Ramsey-Heckscher-Ohlin model with pollution

We formulate a dynamic trade model in continuous time. There are two countries, Home and Foreign. Foreign variables are denoted with an asterisk (*). Two goods, a relatively clean good (X) and a relatively dirty good (Y), are produced using two factors of production, a clean factor and a dirty factor. We assume that the production of the dirty (clean) good is relatively intensive in the dirty (clean) factor of production. These factors can be interpreted as respectively physical capital (K) and emission permits (Z). The initial capital stock is given: K_0 . The clean good is the numeraire and serves a dual function: it is suitable for both investment (I) and consumption (C_x). The dirty good can only be used for consumption (C_y). Such a distinction between the two goods is common in the literature on dynamic H-O models. On the consumption side each household determines its composition of consumption (C) and the path of private assets (A). Households take the level of environmental quality as given. The level of environmental quality is proportional to the level of flow pollution. Pollution is proportional to the use of the dirty input. The government sets the price of emissions (ϑ) to balance the benefits and costs of flow pollution. Pollution damage is local only. In the following we describe the home economy. The foreign economy is similar.

3.1 Consumption

There is an infinitely lived agent who cares only about his or her consumption and environmental quality. Flow pollution is assumed to be harmful for the consumer. Lifetime welfare $\Lambda(t)$ of the agent at time t is given by:

$$\Lambda(t) \equiv \int_t^\infty [U(C_x(s), C_y(s)) - D(Z(s))]e^{-\rho(s-t)}ds \quad (1)$$

with U the utility of consumption D the damage function and ρ the rate of pure time preference. The utility function has the usual properties, including homotheticity. The damage function is increasing and strictly convex in Z , $D'(Z) > 0$, $D''(Z) > 0$ for $Z > 0$. Also, $D(0) = 0$. The representative agent maximizes lifetime welfare subject to the lifetime budget constraint:

$$\int_0^\infty \exp[-\int_0^s r(\tau)d\tau][C_x(s) + p(s)C_y(s)]ds \leq A_0 + T_0$$

where A_0 is the initial amount of assets owned by local residents, r is the gross interest rate, p is the price of the dirty commodity and

$$T_0 \equiv \int_0^\infty \exp[-\int_0^s r(\tau)d\tau]T(s)ds$$

is the lifetime value of discounted government transfers. Transfers $T(t)$ are equal to the government revenues from emission taxation, $T(t) = \vartheta Z(t)$. So, the government has a balanced budget in each period. We also have the household per-period budget identity:

$$\dot{A}(t) = r(t)A(t) + T(t) - C_x(t) - p(t)C_y(t) \quad (2)$$

The change in assets holdings by domestic residents equals the difference in income and expenditures, where income consists of the sum of interest on asset holdings and government transfers. We can retrieve the lifetime budget constraint by integrating the budget identity and applying the appropriate transversality condition, $\lim_{\tau \rightarrow \infty} A(\tau) \exp[-\int_t^\tau r(t)ds] = 0$ ¹. This completes the description of the demand side of the model.

3.2 Production

Firms in each sector $j = x, y$ maximize the present value of current and future profits by buying permits Z_j from the government and renting capital K_j from the investment sector. The technology of production in each sector is subject to constant returns to scale and firms take prices as given. Discounted profits are:

$$\Pi_x(t) = \int_t^\infty [F(K_x(s), Z_x(s)) - r(s)K_x(s) - \vartheta(s)Z_x(s)]e^{-\int_t^s r(\tau)d\tau}ds \quad (3)$$

¹In the next section it will turn out that, since physical capital is the only asset in this economy, the amount of asset holdings by domestic residents equals the stock of physical capital.

$$\Pi_y(t) = \int_t^\infty [p(s)G(K_y(s), Z_y(s)) - r(s)K_y(s) - \vartheta(s)Z_y(s)]e^{-\int_t^s r(\tau)d\tau}ds \quad (4)$$

F (G) is the constant returns to scale production function of the clean (dirty) commodity with diminishing returns to each factor of production. Two remarks are in order with respect to the production technology. Many authors have emphasized that pollution can be equivalently treated as an output or input to production. For example, Z can be seen as the use of environmental services as a firm disposes its waste into the environment. Or, Z can be taken as the number of permits that a firm has to buy in order to be allowed to pollute (See Copeland&Taylor, 2003). To see this, consider a firm that employs capital as the only factor of production and jointly produces a commodity X and emissions Z . The firm has access to an abatement technology that allows it to reduce the pollution intensity of production θ :

$$\begin{aligned} X &= (1 - \theta)F(K_x) \\ Z_x &= e_x(\theta)F(K_x) \end{aligned} \quad (5)$$

with $e_x(\theta) = (1 - \theta)^{\frac{1}{1-\beta}}$. Then we can rewrite the firm's production technology as a production function with capital and emissions as inputs:

$$X = F(K_x)^{1-\beta} Z_x^\beta$$

If $F(K_x)$ takes the form of a simple AK production function the production function effectively turns into a constant returns to scale production function.

From here on we continue with the input-representation of emissions. Either way, there exists a price (tax) ϑ for the use of this input (output). Homogeneity of the production functions allows us to work with output-pollution and capital-pollution ratios. The intensive production functions are denoted by f and g . The first-order conditions for an interior solution can then be rewritten as

$$r(t) = f'(k_x(t)) = p(t)g'(k_y(t)) \quad (6)$$

$$\vartheta(t) = f(k_x(t)) - f'(k_x(t))k_x(t) = p(t)[g(k_y(t)) - g'(k_y(t))k_y(t)] \quad (7)$$

where $k_j \equiv \frac{K_j}{Z_j}$ denotes the capital-permit ratio in sector j . We make the following assumption.

(A1). The production function $f : \mathbb{R}_+ \rightarrow \mathbb{R}_+$ has the usual neo-classical properties, $f(0) = 0$, $f'(k) > 0$, $f''(k) < 0$ for all $k > 0$. In addition $\lim_{k \rightarrow 0} f'(k) = \infty$, $\lim_{k \rightarrow \infty} f'(k) = 0$. The function g has the same properties. Moreover f is more capital-intensive than g , that is, $f(k) > g(k)$ for any $k > 0$.

In the sequel we will amply make use of the concept of the factor price frontier. The factor price frontier of the production function F is the locus of points (r, ϑ) for which maximal profits are zero. It is denoted by $\text{fpf}(F)$. The factor price frontier of G , given the price p , sometimes conveniently phrased as the factor price frontier of pG , is the set of factor prices (r, ϑ) for which maximal profits are zero, at the price p . It is denoted by $\text{fpf}(pG)$. Both loci are decreasing in (r, ϑ) -space, and due to our assumption (A1), $\text{fpf}(F)$ is less steep than $\text{fpf}(pG)$. See figure 1 below.

[INSERT FIGURE 1 HERE]

3.3 Equilibrium

Market equilibrium for permits and for capital requires

$$Z(t) = Z_x(t) + Z_y(t) \quad (8)$$

$$K(t) = K_x(t) + K_y(t) \quad (9)$$

In autarky equilibrium on the goods market prevails if

$$\dot{K}(t) = F(K_x(t), Z_x(t)) - C_x(t) - \delta K(t), \quad K(0) = K_0 \quad (10)$$

$$C_y(t) = G(K_y(t), Z_y(t)) \quad (11)$$

Since we abstract from trade in permits we still have (8) for each country. Since capital is not mobile either, trade is balanced, and net exports equals net imports for both countries. This implies that total income equals total expenditures:

$$F(K_x(t), Z_x(t)) + p(t)G(K_y(t), Z_y(t)) = C_x(t) + p(t)C_y(t) + \delta K(t) + \dot{K}(t) \quad (12)$$

$$F^*(K_x^*(t), Z_x^*(t)) + p(t)G^*(K_y^*(t), Z_y^*(t)) = C_x^*(t) + p(t)C_y^*(t) + \delta K(t)^* + \dot{K}(t)^* \quad (13)$$

and

$$C_y(t) + C_y^*(t) = G(K_y(t), Z_y(t)) + G^*(K_y^*(t), Z_y^*(t)) \quad (14)$$

Regarding environmental policy we assume that the government sets the emission tax equal to marginal damage of pollution. The pollution tax is Pigouvian.

4 Autarky

Since the government internalizes the only external effect a general equilibrium is Pareto efficient. We can therefore characterize the equilibrium by considering the program that maximizes social welfare. So, we look at

$$\max \int_0^\infty [U(C_x(s), C_y(s)) - D(Z(s))] e^{-\rho s} ds \quad (15)$$

subject to (8), (9), (10) and (11). The present-value Hamiltonian reads

$$H = e^{-\rho t} [U(C_x, C_y) - D(Z)] + \bar{\lambda} [F(K_x, Z_x) - C_x - \delta K] + \bar{\mu} [G(K_y, Z_y) - C_y] + \bar{r} [K - K_x - K_y] + \bar{\vartheta} [Z - Z_x - Z_y] \quad (16)$$

There exist a solution to this problem. Given our convexity assumptions it is unique. Moreover, the solution is interior. The necessary conditions read

$$\frac{\partial H}{\partial C_x} = 0 : U_x(C_x(t), C_y(t)) = \lambda(t) \quad (17)$$

$$\frac{\partial H}{\partial C_y} = 0 : U_y(C_x(t), C_y(t)) = p(t)\lambda(t) \quad (18)$$

$$\frac{\partial H}{\partial K_x} = 0 : F_k(K_x(t), Z_x(t)) = r(t) \quad (19)$$

$$\frac{\partial H}{\partial K_y} = 0 : p(t)G_k(K_y(t), Z_y(t)) = r(t) \quad (20)$$

$$\frac{\partial H}{\partial Z_x} = 0 : F_z(K_x(t), Z_x(t)) = \vartheta(t) \quad (21)$$

$$\frac{\partial H}{\partial Z_y} = 0 : p(t)G_z(K_y(t), Z_y(t)) = \vartheta(t) \quad (22)$$

$$\frac{\partial H}{\partial K} = -\dot{\bar{\lambda}} : \dot{\lambda}(t)/\lambda(t) = \rho + \delta - r(t) \quad (23)$$

$$\frac{\partial H}{\partial Z} = 0 : D'(Z(t)) = \vartheta(t)\lambda(t) \quad (24)$$

where $\lambda = e^{\rho t}\bar{\lambda}$, $p = \bar{\mu}/\bar{\lambda}$, $\vartheta = \bar{\vartheta}/\bar{\lambda}$, $r = \bar{r}/\bar{\lambda}$. For the time being we are mainly interested in the steady state, characterized by a constant stock of capital as well as a constant shadow price λ . From $r = \rho + \delta$ and (19) we obtain k_x . Then ϑ follows from (21). Next k_y is retrieved from (20) and (22). We find p from (20) or (22). Let us define

$$\rho + \delta = f'(\omega), \rho + \delta = \bar{p}g'(\psi) \quad (25)$$

$$f(\omega) - f'(\omega)\omega = \bar{p}[g(\psi) - g'(\psi)\psi] \quad (26)$$

$$\bar{\vartheta} = f(\omega) - f'(\omega)\omega \quad (27)$$

Hence ω, ψ, \bar{p} and $\bar{\vartheta}$ are the steady state values of k_x, k_y, p and ϑ , respectively. From (8) and (9) we get

$$z_x \equiv \frac{Z_x}{Z} = \frac{k - \psi}{\omega - \psi} = z_x(k) \quad (28)$$

$$z_y \equiv \frac{Z_y}{Z} = \frac{\omega - k}{\omega - \psi} = z_y(k) \quad (29)$$

with $k = K/Z$. Moreover, from (10) and (11) we have

$$\frac{C_x}{C_y} = \frac{f(\omega)z_x - \delta k}{g(\psi)(1 - z_x)} \quad (30)$$

Since the utility function is homothetic, relative consumption is a function of the relative price only, $\frac{C_x}{C_y} = h(\bar{p})$, where h is a function of \bar{p} . Through $D'(Z) = \bar{\vartheta}(\bar{p})U_x(h(\bar{p}))$ we find the steady state $Z = \bar{Z}$. Substitution of $h(\bar{p})$ into (30) gives us the solution for the autarky aggregate capital-permit ratio :

$$k = \frac{f(\omega)\psi + h(\bar{p})g(\psi)\omega}{f(\omega) + h(\bar{p})g(\psi) - \delta(\omega - \psi)} = \bar{k} \quad (31)$$

Finally, Z_x follows from z_x and \bar{Z} .

Note that capital is monotonically increasing or monotonically decreasing, since it is the only state variable and the solution is unique. Moreover, capital approaches a finite steady state $K = \bar{k}\bar{Z}$. We summarize our findings in the following proposition.

Proposition 1 *Consider the competitive equilibrium of the Ramsey-Hecksher-Ohlin model with pollution. In autarky there exists a unique steady state. The system is globally asymptotically stable.*

Now that we have examined the basic properties of the model under autarky, we turn our attention to a setting with international trade.

5 International trade

In this section we allow for international trade in goods. Trade is balanced in every period. The problem facing an open economy reads

$$\max \int_0^\infty [U(C_x(s), C_y(s)) - D(Z(s))] e^{-\rho s} ds \quad (32)$$

subject to

$$Z(t) = Z_x(t) + Z_y(t) \quad (33)$$

$$K(t) = K_x(t) + K_y(t) \quad (34)$$

$$\dot{K}(t) = F(K_x(t), Z_x(t)) - C_x(t) - \delta K(t) - p(t)X_y(t) \quad (35)$$

$$C_y(t) + X_y(t) = G(K_y(t), Z_y(t)) \quad (36)$$

where X_y is the net export of the clean commodity. The present-value Hamiltonian reads

$$H = e^{-\rho t} [U(C_x, C_y) - D(Z)] \quad (37)$$

$$+ \bar{\lambda} [F(K_x, Z_x) - C_x - p(t)X_y - \delta K] \quad (38)$$

$$+ \bar{\mu} [G(K_y, Z_y) - C_y - X_y] \quad (39)$$

$$+ \bar{r} [K - K_x - K_y] \\ + \bar{\vartheta} [Z - Z_x - Z_y] \quad (40)$$

For consumption the solution is interior. Hence

$$\frac{\partial H}{\partial C_x} = 0 : U_x(C_x(t), C_y(t)) = \lambda(t) \quad (41)$$

$$\frac{\partial H}{\partial C_y} = 0 : U_y(C_x(t), C_y(t)) = p(t)\lambda(t) \quad (42)$$

$$\frac{\partial H}{\partial X_y} = 0 : U_y(C_x(t), C_y(t)) = p(t)\lambda(t) \quad (43)$$

Furthermore the Hamiltonian is maximized with respect to the inputs of each production factor

$$\max F(K_x, Z_x) - r(t)K_x - \vartheta(t)Z_x \quad (44)$$

$$\max p(t)G(K_y, Z_y) - r(t)K_y - \vartheta(t)Z_y \quad (45)$$

$$\frac{\partial H}{\partial K} = -\dot{\bar{\lambda}} : \dot{\lambda}(t) = (\delta + \rho - r(t))\lambda(t) \quad (46)$$

$$\frac{\partial H}{\partial Z} = 0 : D'(Z(t))/\lambda(t) = \vartheta(t) \quad (47)$$

Here $\lambda = e^{\rho t} \bar{\lambda}$, $p = \bar{\mu}/\bar{\lambda}$, $\vartheta = \bar{\vartheta}/\bar{\lambda}$, $\vartheta^* = \bar{\vartheta}^*/\bar{\lambda}$, $r = \bar{r}/\bar{\lambda}$. We interpret r and ϑ as the return on capital and the price of emissions, which is warranted in a first best world. In the next section we will examine the various types of long-run equilibria in this model.

5.1 Identical countries and long-run specialization patterns.

In this section we assume that countries are completely identical in every aspect except (maybe) in terms of their initial capital endowments. Since there are two countries and two commodities there are seven possible candidates for an equilibrium. Of these seven types of equilibria only four are distinct because there are three symmetric pairs. We identify the following equilibrium configurations:

- 1) Imperfect specialization by both countries, denoted by (F, G, F^*, G^*)
- 2) Perfect specialization in the clean good by one country, denoted by (F, G, F^*) or (F, F^*, G^*)
- 3) Perfect specialization in the dirty good by one country; denoted by (G, F^*, G^*) or (F, G, G^*)
- 4) Perfect specialization by both countries; denoted by (G, F^*) or (G, F^*)

We can make general statements with respect to steady state prices, ratios and some quantities regardless of the specific specialization pattern. We summarize this in the following proposition.

Proposition 2 *A steady state is characterized by (i) factor price equalization (FPE) and (ii) equal flows of pollution across countries, $Z = Z^*$. (iii) Across steady states quantities of world capital and world pollution are identical.*

Proof. (i) In a steady we have $r = r^* = \rho + \delta$. Suppose $F > 0$. Then $K_x/Z_x = \omega$ through $f'(\omega) = \rho + \delta$. The permit price follows from $\bar{\vartheta} = f(\omega) - f'(\omega)\omega$. It must be the case that $\vartheta^* \geq \bar{\vartheta}$. Now suppose that $\vartheta^* > \bar{\vartheta}$. This implies $F^* = 0$ because otherwise profits would be negative. Hence $G^* > 0$. From this and the assumption that $\vartheta^* > \bar{\vartheta}$ it follows that home could make unbounded profits by producing Y , since

the home factor prices are lower than the foreign factor prices. This is a contradiction and hence $\vartheta^* = \vartheta$. The same reasoning applies if $F^* > 0$. This completes the first part of the proof.

(ii) As in the case of autarky the steady state value of $K_y/Z_y = \psi$ and the steady state price $p = \bar{p}$ are obtained through the set of equations $\bar{p}g'(\psi) = \rho + \delta$ and $\bar{p}[g(\psi) - g'(\psi)\psi] = \vartheta = \vartheta^*$. Since preferences are homothetic relative consumption is a function of the relative price only, $C_x/C_y = C_x^*/C_y^* = h(p)$ where h is a function of p . Then $\lambda = \lambda^*$ follows from $U_x(C_x/C_y) = U_x(h(p)) = \lambda$. Subsequently $Z = Z^*$ follows from $D'(Z) = \lambda\vartheta = D'(Z^*) = \lambda^*\vartheta^*$. This completes the second part of the proof.

(iii) Denote pollution derived in the previous part of the proof by \bar{Z} . We have, allowing for the possibility that a sector is not active,

$$K = \frac{K_x}{Z_x}Z_x + \frac{K_y}{Z_y}Z_y = \frac{K_x}{Z_x}Z_x + \frac{K_y}{Z_y}(\bar{Z} - Z_x) \quad (48)$$

$$= (\omega - \psi)Z_x + \psi\bar{Z} \quad (49)$$

Similarly

$$K^* = (\omega - \psi)Z_x^* + \psi\bar{Z} \quad (50)$$

So,

$$K + K^* = (\omega - \psi)(Z_x + Z_x^*) + 2\psi\bar{Z} \quad (51)$$

Moreover,

$$C_y + C_y^* = G + G^* \quad (52)$$

$$C_x + pC_y = F + pG - \delta K \quad (53)$$

$$C_x^* + pC_y^* = F^* + pG^* - \delta K^* \quad (54)$$

From utility maximization we have

$$C_x = h(p)C_y \quad (55)$$

$$C_x^* = h(p)C_y^* \quad (56)$$

Hence, after straightforward calculations, and with some abuse of notation

$$\delta(K + K^*) = (Z_x + Z_x^*)(f(\omega) + h(p)g(\psi)) - 2h(p)\bar{Z}g(\psi) \quad (57)$$

Therefore we have two linear equations in the two unknowns $K + K^*$ and $Z_x + Z_x^*$. Hence world capital in the steady state follows:

$$K + K^* = \frac{f(\omega)\psi + h(\bar{p})g(\psi)\omega}{f(\omega) + h(p)g(\psi) - \delta(\omega - \psi)} 2Z = 2k_w^A \bar{Z}$$

where k_w^A denotes the 'world-average' capital-permit ratio. To see that k_w^A is an average we rewrite to see that:

$$k_w^A \equiv \frac{f(\omega)}{f(\omega) + h(p)g(\psi) - \delta(\omega - \psi)} \psi + \frac{h(\bar{p})g(\psi)}{f(\omega) + h(p)g(\psi) - \delta(\omega - \psi)} \omega$$

This completes the final part of the proof. ■

A steady state with imperfect specialization is any pair $\{K, K^*\}$ such that $K + K^* = \bar{K}_w$ and both countries produce both goods. These steady states, as do the others, exhibit a very simplified structure: levels of world income, production, pollution and consumption are equal across steady states. This is a very special result that is uncommon for models with flexible factors of production. The primary reason for this is that the supply of pollution is independent of national income. With Cobb-Douglas utility, the indirect utility function is linear in income. In that case the Samuelson rule states that the marginal rate of substitution between consumption and environmental pollution, $D'(Z)/U_x(h(\bar{p})) = \vartheta(\bar{p})$, is independent of income. As a result, the supply of pollution is only subject to substitution (price) effects². Furthermore, all steady states are characterized by factor price equalization (FPE): interest rates and permit prices are equalized across countries. This is a distinctive feature of our dynamic model. To see why, consider the standard static $2 \times 2 \times 2$ Heckscher-Ohlin framework with labour and capital as factors of production. In this setting FPE and imperfect specialization are two sides of the same coin: if endowments of both countries lie within the so-called FPE set both countries will produce both goods (see Dixit&Norman, 1980). Here, on the other hand, we find that FPE is consistent with specialization in the very long run (cases 2&3). That would imply that true pollution havens might emerge even outside your typical North-South setting (Copeland&Taylor, 1994). Before presenting a diagram that shows all the different steady states in $\{K, K^*\}$ -space, note that there is another property of the model that is worth mentioning:

²A dynamic H-O model with capital and labor as factors of production (and with fixed labor supply in each country) would exhibit a similar steady state with determinate production levels but a-priori unknown trade patterns.

Corollary 3 *The Ramsey-Hecksher-Ohlin model features a scale effect. Under international trade with two countries all world quantities related to production, pollution and capital are exactly twice as large under autarky.*

This observation follows directly from the previous proposition. Interestingly, our model features both neoclassical growth properties and endogenous growth properties. From the AK-model it inherits the scale effect³. In the long-run, however, the model is characterized by zero growth which reminds us of the Ramsey model.

We now derive the conditions under which each of the steady states prevails. Consider the set of equations

$$K + K^* = (\omega - \psi)(Z_x + Z_x^*) + 2\psi\bar{Z} \quad (58)$$

$$\delta(K + K^*) = (Z_x + Z_x^*)(f(\omega) + h(p)g(\psi)) - 2h(p)\bar{Z}g(\psi) \quad (59)$$

In the first equation we have $K + K^* = 2\omega\bar{Z}$ for $Z_x + Z_x^* = 2\bar{Z}$. A necessary and sufficient condition for having a solution with $K + K^* > 0$ and $Z_x + Z_x^* < 2\bar{Z}$ is that $f(\omega) > \delta\omega$. Of course, if one is interested in a steady state this is a natural assumption to make.

Now suppose that there is a steady state with $F > 0, G > 0, F^* > 0, G^* = 0$. Then $K^* = \omega\bar{Z}$ and $Z_x^* = \bar{Z}$. So, the two equations now become

$$K = (\omega - \psi)Z_x + \psi\bar{Z} \quad (60)$$

$$\delta K = Z_x(f(\omega) + h(p)g(\psi)) + \bar{Z}(f(\omega) - h(p)g(\psi) - \delta\omega) \quad (61)$$

We have $\omega - \psi > 0$ and $f(\omega) + h(p)g(\psi)$. So, both lines are upward sloping. Moreover, $f(\omega) + h(p)g(\psi) > \delta(\omega - \psi)$, implying that the latter line is steeper than the former. For $Z = \bar{Z}$ the former yields $K = \omega\bar{Z}$ and the latter gives $K > \omega\bar{Z}$. So, to have an interior solution, with $0 < Z_x < \bar{Z}$ we need $f(\omega) - h(p)g(\psi) < (\omega + \psi)\delta$. Therefore, if $K^* = \omega\bar{Z}$ and if \hat{K} solves these two equations, the steady state is given by $F > 0, G > 0, F^* > 0, G^* = 0$. Obviously, if $K = \omega\bar{Z}$ and if \hat{K} solves these two equations, the steady state is given by $F^* > 0, G^* > 0, F > 0, G = 0$.

Next, suppose that there is a steady state with $F > 0, G > 0, F^* = 0, G^* > 0$. Then $K^* = \psi\bar{Z}$ and $Z_x^* = 0$. So, the two equations now become

³Remember that in section three we discussed the equivalence of our model with a two-sector AK-model.

$$K = (\omega - \psi)Z_x + \psi\bar{Z} \quad (62)$$

$$\delta K = Z_x(f(\omega) + h(p)g(\psi)) - \bar{Z}(2h(p)g(\psi) + \delta\psi) \quad (63)$$

So, again, both lines are upward sloping. Moreover, $f(\omega) + h(p)g(\psi) > \delta(\omega - \psi)$, implying that the latter line is steeper than the former. For $Z = \bar{Z}$ the former yields $K = \omega\bar{Z}$ and the latter gives $K > \omega\bar{Z}$ if and only if $f(\omega) - h(p)g(\psi) > (\omega + \psi)\delta$. If that condition is satisfied we also have $0 < Z_x < \bar{Z}$. Therefore, if $K^* = \omega\bar{Z}$ and if \hat{K} solves these two equations, the steady state is given by $F > 0, G > 0, F^* = 0, G^* > 0$. Obviously, if $K = \omega\bar{Z}$ and if \hat{K} solves these two equations, the steady state is given by $F^* > 0, G^* > 0, F > 0, G = 0$.

Finally, suppose that there is a steady state with $F > 0, G > 0, F^* = 0, G^* > 0$. Then $K = \omega\bar{Z}$ and $K^* = \psi\bar{Z}$. So, $K + K^* = \omega\bar{Z} + \psi\bar{Z}$ is just the average of $2\omega\bar{Z}$ and $2\psi\bar{Z}$. However, the probability that these values satisfy equations (58) and (59) is zero. Hence, we will almost never observe a steady state with perfect specialization. The graph below sketches the steady state equilibrium values of capital.

[INSERT FIGURE 2 HERE]

The identification of the steady state values of capital corresponding with the equilibrium constellations does not yet answer the question of the stability of these values. Nor does it solve the way in which convergence, if any, takes place. This is subject to further research. A final observation that can be made from the previous conditions is that steady states of type 2,3 and 4 are mutually exclusive. To see this, we define:

$$\Psi \equiv f(\omega) - h(\bar{p})g(\psi) - \delta(\omega + \psi)$$

and K^w as the solution of (58) and (59). Then we can summarize the previous results in the following proposition:

Proposition 4 *There exists a steady state if and only if $f(\omega) > \delta\omega$. Moreover,*

- 1) $FGF^*G^* \Leftrightarrow K + K^* = K^w$ and $\psi\bar{Z} < (K, K^*) < \omega\bar{Z}$
- 2) $FGF^* \Leftrightarrow \Psi < 0, K + K^* = K^w$ and $K^* = \omega\bar{Z}$
- 3) $FGG^* \Leftrightarrow \Psi > 0, K + K^* = K^w$ and $K^* = \psi\bar{Z}$
- 4) $FG^* \Leftrightarrow \Psi = 0$ and $K + K^* = K^w$ and $K^* = \psi\bar{Z}$ and $K = \omega\bar{Z}$

The following figure depicts a numerical example of a Lerner diagram for which $\Psi < 1$. Recall that the Lerner diagram in static trade models

divides a certain endowment space into various compartments. One can then relate all endowment points within a particular subspace to a specific trade pattern.

[INSERT FIGURE 3 HERE]

In figure 4 we have drawn the cone of specialization with steady states of type 1 (FGF^*G^*) and 2 (FGF^* and FF^*G^*) for a particular set of parameter values. The graph shows how the steady states are ordered in $\{K, K^*\}$ -space. It can best be understood by first describing the various lines that divide the space in 6 subspaces (A, B, C, D, E, F). First, there is a straight line on which the quantity of world capital is fixed. Its intercepts with the K -axis and K^* -axis are giving the coordinates $(0, 2k_w^A Z)$ and $(2k_w^A Z, 0)$. Second, there are two radial lines from the origin with respectively slopes of size $\frac{(k+k^*)-k_x}{k_x} < 1$ and $\frac{k_x}{(k+k^*)-k_x} > 1$. These two lines encapsulate the red segment of the K_w -line that is consistent with imperfect specialization in both countries. In addition, type 2 specialization patterns are found at the edges of the K_w -line.

Next, let us denote the steady state capital stock of home (foreign) under specialization type i by K_i (K_i^*). When Foreign (Home) is specialized in the clean good we observe that K_2^* (K_2) is strictly larger than any K_1^* , (K_1) that is, $K_2^* \geq K_1^*$ ($K_2 \geq K_1$). In other words, the steady states with perfect specialization by one of the two countries in the clean good can be found at the upper-left and bottom-right of the K_w -line. The explanation is intuitive. For home to specialize completely in the clean good it has to have a relatively large aggregate capital-permit ratio when compared with imperfect specialization, $k_2 \geq k_1$. Since $Z_1 = Z_2$ this also directly implies that $K_2 \geq K_1$. Finally, steady state welfare in the country that is perfectly specialized in the clean good is strictly larger than under imperfect specialization. Since pollution damages are equal in all allocations a sufficient condition is that income under complete specialization is higher than under imperfect specialization:

$$I_2 = rK_2 + \vartheta Z > rK_1 + \vartheta Z = I_1.$$

which follows directly from $K_2 \geq K_1$. This result can be repeated for Foreign as well. That welfare is higher under complete specialization than under imperfect specialization is a typical result in Ricardian trade theory. Here it is often acknowledged that the largest gains from trade are for the small country that specializes completely. Here, 'small' should be interpreted as having a relatively small steady state capital endowment.

5.2 Is a patient nation a dirty nation?

In this section we focus on the effects of differences in the rates of pure time preference. We will keep all other characteristics, such as utility functions, damage functions and production functions identical. Studying the properties of steady states in this case is interesting for at least two reasons. Firstly, economists have been preoccupied with this issue in a trade context for a very long time. A seminal publication in this field is by Stiglitz (1970), who studies cross-country differences in discount rates in a Solow-Heckscher-Ohlin model. Secondly, environmental economists have had a long tradition of interest in the magnitude of the discount rate. This is mainly because many environmental problems come into play in the far future and are likely to be with us for many generations. Surprisingly, differences in the pure rate of time preference between regions and countries is not very often considered in the field. Our environmental specification is rather simple, but having said that, we still feel that our basic setting is interesting enough to study the relation between regional differences in discount rates on the one hand and its effects on regional pollution flows on the other hand.

We consider the case where $\rho > \rho^*$. In the long run $\rho + \delta = r > \rho^* + \delta = r^*$. Clearly we cannot have incomplete specialization in both countries, because that would require equal interest rates. This is summarized in the following proposition.

Proposition 5 *If $\rho + \delta > \rho^* + \delta$ then factor price equalization (FPE) across countries in the steady state breaks down. At least one country will specialize completely.*

Proof. Since $\rho > \rho^*$ we have that $r > r^*$. This proves the first part of the proposition. Suppose that both countries are imperfectly specialized. Then (r, ϑ) as well as (r^*, ϑ^*) are on the factor price frontier of F as well as on the factor price frontier of pG , which is not possible. This completes the second part of the proof. ■

We show that in principle three steady state trade constellations are feasible:

Proposition 6 *If $\rho + \delta > \rho^* + \delta$ the global steady state has only three possible configurations:*

- 1) *imperfect specialization by Home and perfect specialization by Foreign in the clean good*
- 2) *imperfect specialization by Foreign and perfect specialization by Home in the dirty good*

3) *perfect specialization by both countries: Home (Foreign) produces the dirty (clean) good*

Proof. Suppose $F > 0$. Then $\vartheta^* \geq \vartheta$ because otherwise foreign can make unbounded profit in the clean good production. If $G^* > 0$ then the pair (r, ϑ) lies below the factor price frontier corresponding with pG . This is not feasible. Hence $G^* = 0$. Hence $G > 0$ and $F^* > 0$, the latter holding since the foreign country will use its capital.

Suppose $F = 0$. Then it follows that $G > 0$ and $F^* > 0$. Then $\vartheta \geq \vartheta^*$. It is possible that $G^* > 0$. So we have either GF^*G^* or GF^* .

This completes the proof. ■

The analysis of the different cases is analogous to what we did for equal rates of time preference.

Consider the steady state with $F > 0, G > 0, F^* > 0, G^* = 0$. Define $\omega, \omega^*, \vartheta, \vartheta^*, p$ and ψ by $\rho + \delta = F_k(\omega)$, $\vartheta = F_z(\omega)$, $\rho^* + \delta = F_k(\omega^*)$, $\vartheta^* = F_z(\omega^*)$, $pG_k(\psi) = \rho + \delta$, and $pG_z(\psi) = \vartheta$. Moreover, $D'(\bar{Z}) = \lambda\vartheta$ and $D'(\bar{Z}^*) = \lambda\vartheta^*$ with λ following from utility maximization. It is immediately clear that $\vartheta < \vartheta^*$, implying $\bar{Z} < \bar{Z}^*$. Hence the patient country is suffering more pollution. Then, in the case at hand, $K^* = \omega^*\bar{Z}^*$ and $Z_x^* = \bar{Z}^*$. So, the two equations now become

$$K = (\omega - \psi)Z_x + \psi\bar{Z} \quad (64)$$

$$\delta K = (F(\omega) + h(p)G(\psi))Z_x + \bar{Z}^*F(\omega^*) - \bar{Z}h(p)G(\psi) - \bar{Z}^*\delta\omega^* \quad (65)$$

We can now pursue the same analysis as we did earlier to determine the initial capital stocks that will yield this configuration as a steady state. So, to have an interior solution, with $0 < Z_x < \bar{Z}$ we need

$$\bar{Z}^*f(\omega^*) - \bar{Z}h(p)g(\psi) < \bar{Z}^*\delta\omega^* + \bar{Z}\delta\psi$$

This condition is similar to the condition $f(\omega) - h(p)g(\psi) < (\omega + \psi)\delta$ that was needed for the existence of this type of equilibrium with equal discount rates.

Next, suppose that there is a steady state with $F > 0, G > 0, F^* = 0, G^* > 0$. Then

$$K = (\omega - \psi)Z_x + \psi\bar{Z} \quad (66)$$

$$\delta K = (f(\omega) + h(p)g(\psi))Z_x - \bar{Z}^*h(p)g(\psi^*) - \bar{Z}h(p)g(\psi) - \bar{Z}^*\delta\omega^* \quad (67)$$

In a similar way as before we find that a necessary and sufficient condition for an interior solution for home pollution and capital is

$$\bar{Z}f(\omega) - \bar{Z}^*h(p)g(\psi^*) > \bar{Z}^*\delta\psi^* + \bar{Z}\delta\omega$$

Note that, contrary to the case of equal rates of time preference, the two conditions are not mutually exclusive. However, they are for $G > 0$, $F^* > 0$ and $G^* > 0$

Complete specialization offers an interesting case. Clearly we must have $G > 0, F^* > 0$. Then K/Z is a function of p through $pG_k = \rho + \delta$ and ϑ is then also a function of p through $pG_z = \vartheta$. We find K^*/Z^* and ϑ^* through $F_k = \rho^* + \delta$ and $F_z = \vartheta^*$. Again $\lambda = \lambda^*$ and they follow from utility maximization, as a function of p . Then we find Z and Z^* using $D'(Z) = \lambda\vartheta$ and $D'(Z^*) = \lambda\vartheta^*$, both as a function of p . We also have, as before,

$$\delta(K/Z)Z + \delta(K^*/Z^*)Z^* = Z^*F(K^*/Z^*) - h(p)ZG(K/Z) \quad (68)$$

Since all variables involved only depend on p we can solve for p and subsequently for all other variables. This then yields a unique set of initial capital stocks for which complete specialization prevails in a steady state. Of course it has to be checked whether the price is in between the prices prevailing in the relevant cases of incomplete specialization.

Corollary 7 *In the long-run the relative impatient country will be a pollution haven.*

Note that this observation is independent of the specific trade pattern that comes about. The previous proposition showed that if $\rho > \rho^*$ home (foreign) is always a producer of the dirty (clean) good. From this it directly follows that home will always be an exporter of the dirty good. Should we expect this result to go through in more general models? Not necessarily. Our model has assumed the accumulation of a perfectly clean factor. Various additions to the literature on trade and the environment have assumed a correlation between capital-intensity and emission intensity in models with three factors of production (labour, capital and emissions) (Copeland&Taylor, 2003). Incorporating this correlation into our model might lead us to find that the patient country will be an exporter of the dirty good. This would completely overturn our finding. Nevertheless, we can state that regional differences in ρ are sure to lead to regional differences in production patterns.

We now introduce an example for illustrative purposes.

Example 8 Take $U = C_x^\alpha C_y^{1-\alpha}$, $D(Z) = \frac{Z^{1+\eta}}{1+\eta}$, $F = K_x^\beta Z_x^{1-\beta}$ and $G = K_y^\gamma Z_y^{1-\gamma}$.

The possibility of complete specialization can be illustrated as follows. In that case we have

$$\frac{K}{Z} = \left(\frac{\rho + \delta}{\gamma p} \right)^{\frac{1}{\gamma-1}}; \vartheta = p(1 - \gamma) \left(\frac{\rho + \delta}{\gamma p} \right)^{\frac{\gamma}{\gamma-1}} \quad (69)$$

$$\frac{K^*}{Z^*} = \left(\frac{\rho^* + \delta}{\beta} \right)^{\frac{1}{\beta-1}}; \vartheta^* = (1 - \beta) \left(\frac{\rho^* + \delta}{\beta} \right)^{\frac{\beta}{\beta-1}} \quad (70)$$

Also

$$\lambda = \lambda^* = \alpha^\alpha (1 - \alpha)^{1-\alpha} p^{\alpha-1} \quad (71)$$

Therefore

$$Z^\eta = \alpha^\alpha (1 - \alpha)^{1-\alpha} p^{\alpha-1} p(1 - \gamma) \left(\frac{\rho + \delta}{\gamma p} \right)^{\frac{\gamma}{\gamma-1}} \quad (72)$$

and

$$(Z^*)^\eta = \alpha^\alpha (1 - \alpha)^{1-\alpha} p^{\alpha-1} (1 - \beta) \left(\frac{\rho^* + \delta}{\beta} \right)^{\frac{\beta}{\beta-1}} \quad (73)$$

Moreover, as before

$$C_y + C_y^* = G \quad (74)$$

$$C_x + pC_y = pG - \delta K \quad (75)$$

$$C_x^* + pC_y^* = F^* - \delta K^* \quad (76)$$

implying

$$(1 - \alpha)\delta K = (1 - \alpha)F^* - \alpha pG - (1 - \alpha)\delta K^* \quad (77)$$

So,

$$(1 - \alpha)\delta(K/Z)Z = (1 - \alpha)Z^*F(K^*/Z^*, 1) - \alpha pZG(K/Z, 1) - (1 - \alpha)\delta(K^*/Z^*)Z^* \quad (78)$$

The expressions for K/Z and K^*/Z^* as functions of p only are known. This then leads to the following equation for p :

$$\left(\frac{p^{\frac{1}{1-\gamma}} (1 - \gamma) \left(\frac{\rho + \delta}{\gamma} \right)^{\frac{\gamma}{\gamma-1}}}{(1 - \beta) \left(\frac{\rho^* + \delta}{\beta} \right)^{\frac{\beta}{\beta-1}}} \right)^{1/\eta} = \frac{(1 - \alpha) \left(\frac{\rho^* + \delta}{\beta} \right)^{\frac{\beta}{\beta-1}} - \delta(1 - \alpha) \left(\frac{\rho^* + \delta}{\beta} \right)^{\frac{1}{\beta-1}}}{\alpha p^{\frac{1}{1-\gamma}} \left(\frac{\rho + \delta}{\gamma} \right)^{\frac{\gamma}{\gamma-1}} + \delta(1 - \alpha) p^{\frac{1}{1-\gamma}} \left(\frac{\rho + \delta}{\gamma} \right)^{\frac{1}{\gamma-1}}} \quad (79)$$

From this equation we can solve p and subsequently Z and Z^* . Finally we can find the K and K^* needed for this equilibrium to occur.

This result can easily be illustrated in an (r, ϑ) diagram. In figure 4 we have depicted the factor price frontier of F and we have fixed $r = \rho + \delta$ and $r^* = \rho^* + \delta$. The points E_1 correspond with an equilibrium where $F > 0, G > 0$ and $F^* > 0$. The points E_2 correspond with $F = 0, G > 0, F^* > 0$ and $G^* > 0$. But the latter configuration can also correspond with complete specialization. However, a clear cut example of an equilibrium with complete specialization is given by the points E_3 .

[INSERT FIGURE 4 HERE]

The previous proposition reveals two interesting tendencies with respect to the patterns of production and trade when Home is more patient than Foreign. Firstly, the tendency towards a more specialized production pattern. Why is this the case? Imperfect specialization becomes impossible since factor prices are no longer equalized. Hence, at least one of the two countries becomes perfectly specialized. In addition, the global production pattern is more orientated towards the relatively dirty good. With the world now being more impatient 'on average' we find that ceteris paribus the steady state levels of capital are lower. From the Rybczynski theorem we then know that world production will increase in the direction of the dirty good, and more than proportionally so. Secondly, the direction of the inequality $\rho \geq \rho^*$ is a predictor of the trade pattern.

Corollary 9 *In the long-run the relative impatient country will be a pollution haven.*

Note that this observation is independent of the specific trade pattern that comes about. The previous proposition showed that if $\rho > \rho^*$ home (foreign) is always a producer of the dirty (clean) good. From this it directly follows that home will always be an exporter of the dirty good. Should we expect this result to go through in more general models? Not necessarily. Our model has assumed the accumulation of a perfectly clean factor. Various additions to the literature on trade and the environment have assumed a correlation between capital-intensity and emission intensity in models with three factors of production (labour, capital and emissions) (Copeland&Taylor, 2003). Incorporating this correlation into our model might lead us to find that the patient country will be an exporter of the dirty good. This would completely overturn our finding.

Proposition 10 *Suppose $\rho > \rho^*$. Then in the global steady state Home will be a Pollution Haven. In addition, we can categorize the following long-run specialization patterns:*

Normal Pollution Haven (FGF^): Home produces both goods and Foreign produces only clean goods if*

$$\bar{Z}^* f(\omega^*) - \bar{Z} h(p) g(\psi) < \bar{Z}^* \delta \omega^* + \bar{Z} \delta \psi$$

*True Pollution Haven (GF^*G^*): Home produces only dirty goods and Foreign produces both goods if*

$$\bar{Z}^* f(\omega^*) - \bar{Z} h(p) g(\psi) > \bar{Z} \delta \psi + \bar{Z}^* \delta \omega^*$$

Let us now focus on the intuition behind the emergence of the three different specialization patterns. First, note that Home (Foreign) will always produce the dirty (clean) good. The reason is that the relatively patient country will have accumulated a relative large capital stock in the steady state. Ceteris paribus this implies that Foreign, the relatively patient country, will have a comparative advantage in the clean good. Second, what determines the exact specialization pattern in the steady state are the consumer preferences. In the case of the Cobb-Douglas utility function above, α indicates the relative preference for the clean commodity. Therefore, an increase in α will increase the likelihood of a normal pollution haven, where both countries produce the clean commodity. A further sensitivity analysis is subject to further research. But it can be shown that

Corollary 11 *For $\rho > \rho^*$ ($\rho < \rho^*$) an increase (decrease) in relative environmental preferences η^*/η will increase the likelihood of both countries producing the dirty good in the steady state.*

6 Conclusion

The question of who produces what for whom becomes especially interesting when the 'what' involves environmental degradation. With the rise of China as the manufacturer of the world this question has become all the more pressing. No wonder that the topic of trade and the environment continues to evoke discussion in environmental economics. In this paper we have tried to give what we hope is a new and interesting perspective on the pollution haven hypothesis. We have done so by emphasizing the dynamic nature of the problem. In our view this

asks for an integrated picture of trade, growth and the environment. Our main method of analysis is dynamic trade theory. We construct a two-country Ramsey-Heckscher-Ohlin model with pollution to consider (i) long-run specialization patterns when countries are completely identical and (ii) the effects of cross-country differences in the subjective discount rate on long-run trade patterns. First, we find that with identical countries there are several long-run equilibria with both imperfect specialization and perfect specialization. All steady states are characterized by factor price equalization. Interestingly, the steady state level of flow pollution is independent of the specific specialization pattern that is obtained. Second, we find that if countries differ with respect to the rate of time preference, an important and deep parameter in environmental economics, at least one country will specialize completely. This holds for the model in general as well as for the steady state. It opens up the possibility for so-called true pollution havens: complete specialization in production of the dirty good by the impatient country. This contrasts with earlier results in the literature that stressed imperfect specialization by all trade partners. Since the dirty good is used only for consumption, true pollution havens are more likely when consumer preferences for the dirty good are relatively high.

In the previous sections we discussed various long-run implications of our dynamic trade model. Interesting as this may be, we have not yet explored local and global dynamics. For example, the question whether a country will always be a pollution haven once it has 'started out' as one, cannot be answered without referring to transitional dynamics. In future work we hope to address these issues in framework(s) that are closely related to the one that we have set out in this paper. More in general, theoretical research in the trade-growth-environment nexus has primarily delivered papers that are either 'trade' or 'growth', but not both. Although such a strict focus has led to many interesting insights, there are theoretical and empirical reasons that demand an integrated approach.

From a theoretical point of view one can disentangle two reasons for an integrated approach. First, asking old questions in a new framework might yield important new results by itself. For example, the Green Solow model (Brock&Taylor, 2008) shows us that a rather standard growth model with diminishing returns to capital and technological progress in abatement yields an environmental Kuznets curve. It also explains that the point in time that is associated with a peak level of emissions depends on initial conditions. An integrated model of the world economy might yield several new insights in this area. One might be able to derive an EKC for the world as a whole and relate it to the

distribution of production and income across countries. Can an EKC for the world as a whole be consistent with periods where emission levels increase for one country while they are decreasing for another? And how is the cross-country timing of peak levels in emissions affected by international trade? How are export patterns related to (relative) emissions growth rates across countries? Can a country that is on the downward sloping part of its EKC still be a pollution haven?

Second, an integrated approach allows us to ask questions that are new by itself. For example, empirical evidence indicates that emissions intensity differs more across countries than across industries. In addition, there is evidence that laggard countries adopt cleaner technologies at a lower level of income than early adopters. Finally, many technologies, environmental or otherwise, are embodied in capital equipment. Empirical evidence for the U.S indicates that capital investment is responsible for more than 50% of technological progress. One possibility to reconcile this conflicting evidence is to construct a dynamic trade model where capital is heterogeneous, i.e., vintage capital. If technology is embodied in capital, developing countries will use older, dirtier vintages for production because they are cheaper and regulation is less stringent in these countries. A recent paper by Eaton & Kortum (2001) might be useful in this regard. Finally, empirical methodologies that are constructed by applying closed economy models are no substitute for ones that are derived from open economy models. Other interesting topics in international economics have already proved this (See for example Matsuyama (2008) on the relationship between differences in cross-country productivity growth in the manufacturing sector and the decline of the manufacturing sector in certain parts of the world).

Another interesting avenue for future research is to study the relationship between (cross-country differences in) environmental policy and growth convergence in dynamic factor-proportions models with forward-looking behavior. Recently, a lot of progress has been made in related work that stresses the interaction between growth and trade in the world economy (Ventura (1997), Acemoglu & Ventura (2002) and Ventura (2005)). For example, by combining i) a dynamic version of the factor price equalization result of international trade and the ii) Ramsey model, Ventura (1997) shows how poor countries can grow faster than rich countries if and only if factor prices do not change too fast as the world economy grows. Once they are integrated in the world economy, 'international trade converts an excess production of capital-intensive goods into exports, instead of falling prices (Ventura, 1997)'. However, this conditional convergence result only holds after controlling for government policies. It might turn out that cross-country (income-dependent)

variations in environmental policy affect convergence. Related to this question, is it true that once a country is a pollution haven it will remain so forever? Can government policies overturn this outcome? Or can they only marginally affect a country's share in world production of dirty commodities? We hope to answer some of these questions in future work.

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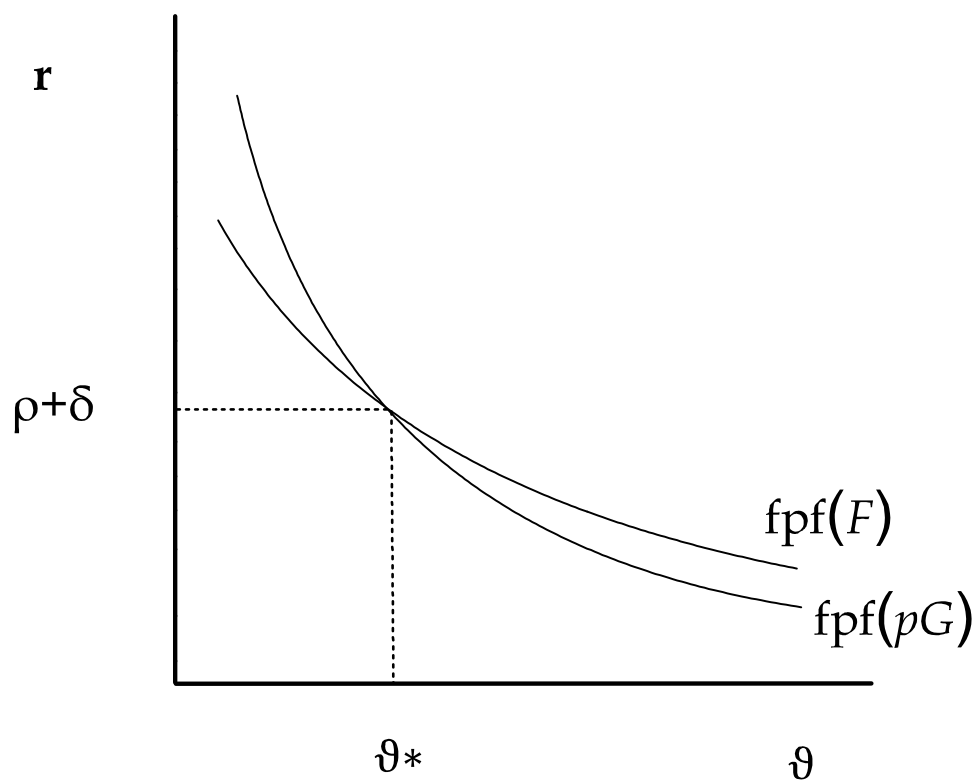


Figure 1: Figure 1: Factor Price Frontiers

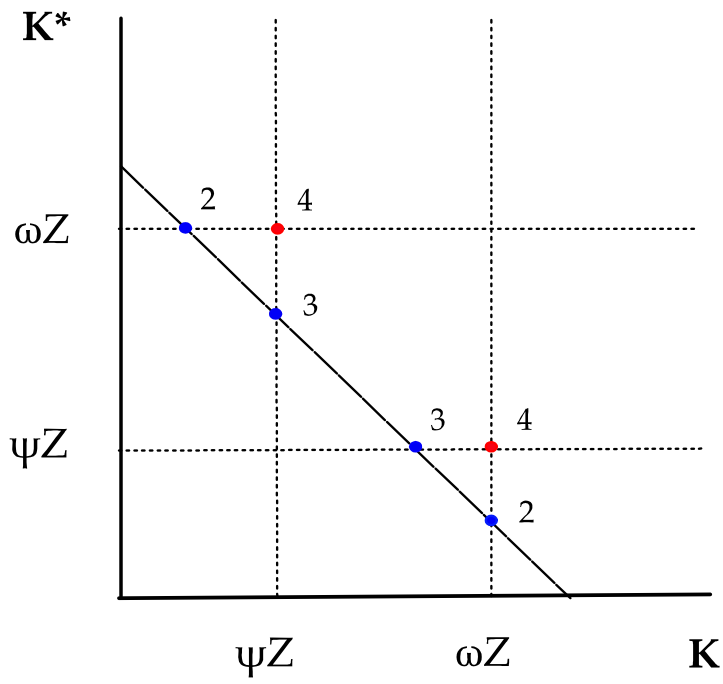


Figure 2: Figure 2 : Cone of Specialization

7.1 Figures

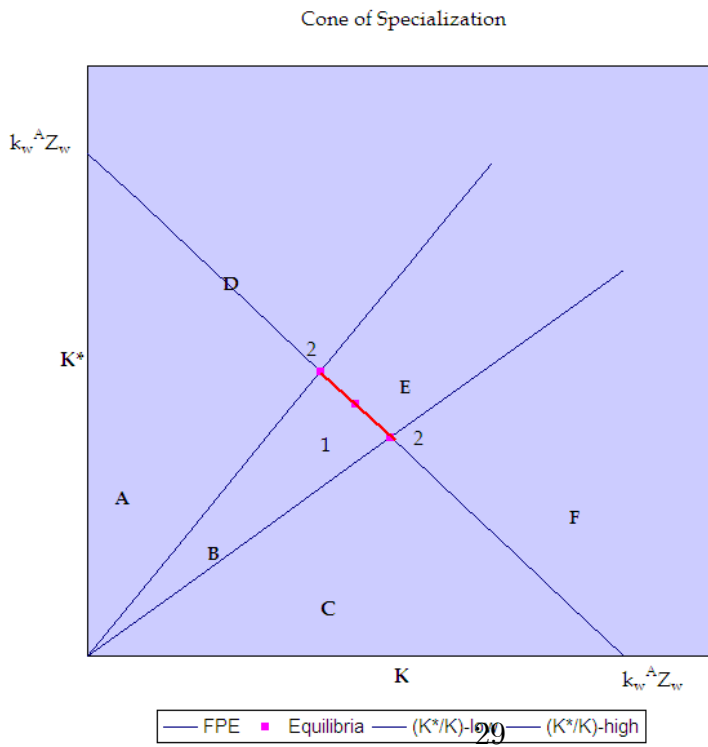


Figure 3: Lerner Diagram with $\Psi < 1$.
 $\rho^* = \rho = 0.03, \beta = 0.7, \gamma = 0.6, \alpha = 0.5, \delta = 0.07, \eta = \eta^* = 1$

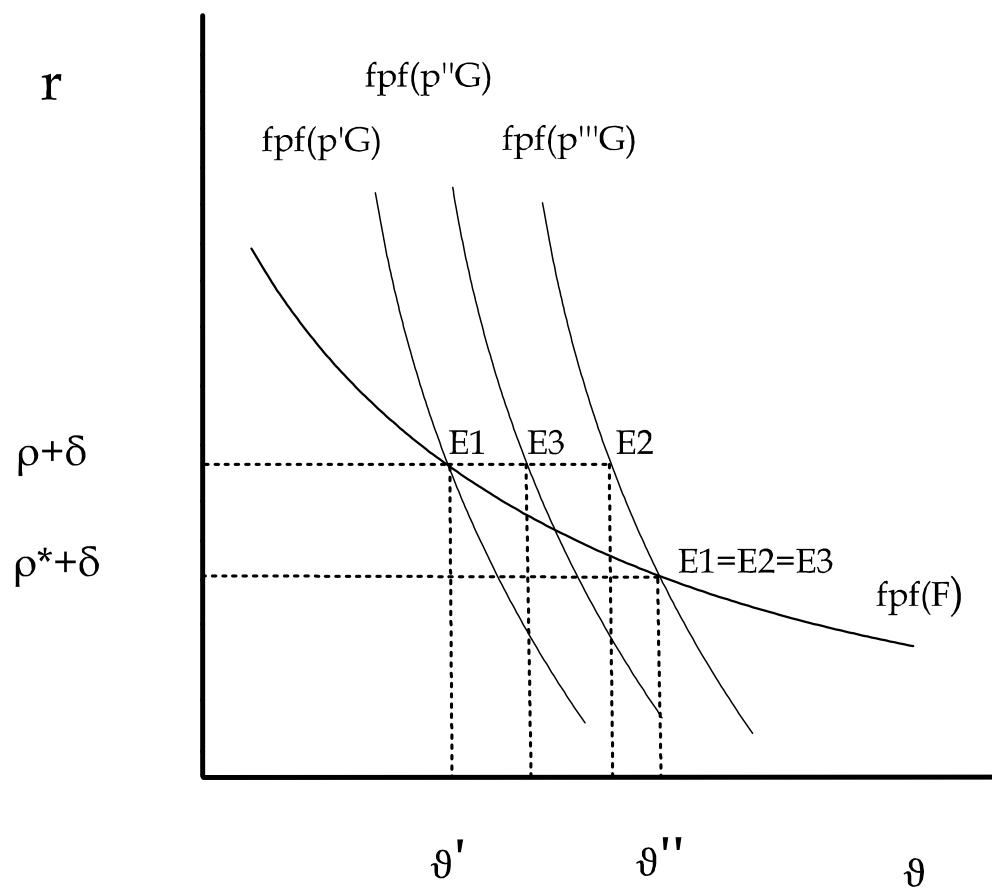


Figure 3: Figure 4: Home is Impatient